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- It is acceptable to assume that all measured sulfate is in the form of ammonium sulfate $[(\text{NH}_4)_2\text{SO}_4]$ and all particulate nitrate is in the form of ammonium nitrate $[\text{NH}_4\text{NO}_3]$.

To facilitate tracking the progress toward visibility goals, two important visibility parameters are required for each Class I area:

- *Baseline Conditions*: “Baseline Conditions” represent visibility for the B20% and W20% days for the initial five-year baseline period of the regional haze program. Baseline Conditions are calculated using monitoring data collected during the 2000-2004 five-year period and are the starting point in 2004 for the uniform rate of progress (URP) glide path to Natural Conditions in 2064 (U.S. EPA, 2003b).
- *Natural Conditions*: “Natural Conditions,” the RHR goal for 2064 for the Federally mandated Class I areas, represent estimates of natural visibility conditions for the B20% and W20% days at a given Class I area.

3.3.1 Calculation of Baseline Conditions

Baseline Conditions for Class I areas are calculated using fine and coarse PM concentrations measured at Interagency Monitoring of Protected Visual Environments (IMPROVE) monitors (Malm et al., 2000). Each Class I area in the WRAP domain has an associated IMPROVE PM monitor. The IMPROVE monitors do not measure visibility directly, but instead measure speciated fine particulate ($\text{PM}_{2.5}$) and total $\text{PM}_{2.5}$ and PM_{10} mass concentrations from which visibility is calculated using the IMPROVE aerosol extinction equation, discussed later.

Visibility conditions are estimated starting with the IMPROVE 24-h average PM mass measurements related to six PM components of light extinction:

- Sulfate $[(\text{NH}_4)_2\text{SO}_4]$
- Particulate nitrate $[\text{NH}_4\text{NO}_3]$
- Organic matter [OMC]
- Light-absorbing carbon [LAC] or elemental carbon [EC]
- Soil
- Coarse matter [CM]

The IMPROVE monitors do not directly measure some of these species, so assumptions are made as to how the IMPROVE measurements can be adjusted and combined to obtain these six components. For example, sulfate and particulate nitrate are assumed to be completely neutralized by ammonium and only the fine mode ($\text{PM}_{2.5}$) is speciated to obtain sulfate and nitrate measurements (that is, any coarse-mode sulfate and nitrate in the real atmosphere may be present in the IMPROVE CM measurement). Concentrations for the above six components of light extinction in the IMPROVE aerosol extinction equation are obtained from the IMPROVE measured species using the formulas shown in Table 3-1.

Table 3-1. Definition of IMPROVE components from measured species.

IMPROVE Component	Calculation of Component from IMPROVE Measured Species
Sulfate	$1.375 \times (3 \times S)$
Nitrate	$1.29 \times \text{NO}_3^-$
OMC	$1.4 \times \text{OC}$
LAC	EC
Soil	$(2.2 \times \text{Al}) + (2.49 \times \text{Si}) + (1.63 \times \text{Ca}) + (2.42 \times \text{Fe}) + (1.94 \times \text{Ti})$
CM	MT – MF

where

- S is elemental sulfur as determined from proton-induced x-ray emissions (PIXE) analysis of the IMPROVE Module A. To estimate the mass of the sulfate ion (SO_4^{2-}), S is multiplied by 3 to account for the presence of oxygen. If S is missing then the sulfate (SO_4) measured by ion chromatography analysis of Module B is used to replace $(3 \times S)$. For the IMPROVE aerosol extinction calculation, sulfate is assumed to be completely neutralized by ammonium ($1.375 \times \text{SO}_4$).
- NO_3^- is the particulate nitrate measured by ion chromatography analysis of Module B. For the IMPROVE aerosol extinction calculation, it is assumed to be completely neutralized by ammonium ($1.29 \times \text{NO}_3$).
- The IMPROVE organic carbon (OC) measurements are multiplied by 1.4 to obtain organic matter (OMC), which adjusts the OC mass for other elements assumed to be associated with OC.
- Elemental carbon (EC) is also referred to as light-absorbing carbon (LAC).
- Soil is determined as a sum of the masses of those elements (measured by PIXE) predominantly associated with soil (Al, Si, Ca, Fe, K, and Ti), adjusted to account for oxygen associated with the common oxide forms. Because K is also a product of the combustion of vegetation, it is represented in the formula by $0.6 \times \text{Fe}$ and is not shown explicitly.
- MT and MF are total PM_{10} and $\text{PM}_{2.5}$ mass, respectively.

Associated with each PM species is an extinction efficiency that converts concentrations (in $\mu\text{g}/\text{m}^3$) to light extinction (in inverse megameters, Mm^{-1}), as listed below. Sulfate and nitrate are hygroscopic, so relative humidity (RH) adjustment factors, $f(\text{RH})$, are used to increase the particles' extinction efficiency with increasing RH; this accounts for the particles' taking on water and having greater light scattering. Note that some organic matter (OMC) compounds may also have hygroscopic properties, but the IMPROVE aerosol extinction equation assumes OMC is nonhygroscopic.

$$\beta_{\text{Sulfate}} = 3 \times f(\text{RH}) \times [\text{sulfate}]$$

$$\beta_{\text{Nitrate}} = 3 \times f(\text{RH}) \times [\text{nitrate}]$$

$$\beta_{\text{OMC}} = 4 \times [\text{OMC}]$$

$$\beta_{\text{EC}} = 10 \times [\text{EC}]$$

$$\beta_{\text{Soil}} = 1 \times [\text{soil}]$$

$$\beta_{\text{CM}} = 0.6 \times [\text{CM}]$$

The total light extinction (β_{ext}) is assumed to be the sum of the light extinctions due to the six PM species listed above plus Rayleigh (blue sky) background extinction (β_{Ray}), which is assumed to be 10 Mm^{-1} . This is reflected in the IMPROVE extinction equation:

$$\beta_{\text{ext}} = \beta_{\text{Ray}} + \beta_{\text{Sulfate}} + \beta_{\text{Nitrate}} + \beta_{\text{EC}} + \beta_{\text{OMC}} + \beta_{\text{Soil}} + \beta_{\text{CM}}$$

The total light extinction (β_{ext}) in Mm^{-1} is related to visual range (VR) in kilometers using the following relationship:

$$\text{VR} = 3912 / \beta_{\text{ext}}$$

The RHR requires that visibility be expressed in terms of a haze index (HI) in units of deciview (dv), which is calculated as follows:

$$\text{HI} = 10 \ln(\beta_{\text{ext}}/10)$$

The equations above, with measurements from the associated IMPROVE monitor, are used to estimate the daily average visibility at each Class I area for each IMPROVE monitored day. For each year from the 2000-2004 baseline period, these daily average visibility values are then ranked from highest to lowest. The “worst days” visibility for each of the five years in the baseline period is defined as the average visibility across the 20% worst-visibility days (highest deciview values); similarly, the “best days” visibility is defined as the average visibility across the 20% best-visibility days (lowest deciview values) for each year. The Baseline Conditions for the best and worst days are defined as the five-year average of the B20% visibility days and of the W20% visibility days, respectively, across the five-year baseline period.

The set of equations given above for relating measured PM species to visibility (light extinction) are referred to as the “Old IMPROVE” equation. The IMPROVE Steering Committee has developed a “New IMPROVE” equation that they believe better represents the fit between measured PM species concentrations and visibility impairment. Although conceptually similar to the Old IMPROVE equation, the New IMPROVE equation includes updates to many of the parameters and the addition of extinctions due to NO_2 absorption and sea salt. We performed 2018 visibility projections and comparisons with the URP glide path goals using both the New and Old IMPROVE equations. The reader is referred elsewhere for details on the New IMPROVE extinction equation (e.g., EPA, 2006a,b).